**Introduction:** Welcome to the Omicron Theta Epsilon Biology seminar series, yet again. I'm thrilled to posting it our guest today. Seminar speaker will be Dr. Marc Epstein of the California Department of Food and Agriculture. Dr. Epstein has been the Senior Insect Biosystematist at the CDFA for the past 10 years, before that he was at the Smithsonian Institution for 15 years and this was following his PhD work at the University of Minnesota and his interest in six legged creatures including butterflies, moths, beetles and the like, this goes way back. He and I had something in common both of us at the age of 4 expressed an early interest in butterflies. So, I need to point that out. Among other things, Dr. Epstein has appeared with Terry Gross on Fresh Air and he has a continuing interest in playing the clarinet. He describes his music as an eclectic Klezmer. You're going to have to ask exactly what that means. And the title of Dr. Epstein's talk is, "I got your back: My Movies and Research on the Evolution of the Defense and Locomotion of Slug and Nettle Caterpillar Moths, 1989 to the present.

**Dr. Epstein:** So, first the question, do you know what an “instar” is? Raise your hand if you do. An instar is--and I'm going to use that word a lot because we're talking about caterpillars, and of course you know that insects have different stages of metamorphosis and some, like moth and butterflies. go through what's called complete metamorphosis. So, they have the adult stage, the egg stage, the larval stage, and the pupa stage. But what's less known is that -- and of course the pupa stages what we often called butterfly is the chrysalis and a cocoon is a silk in covering of the pupa. So, it's like, if butterflies build a cocoon their chrysalis would be covered.
with silk. But anyway, in order to grow caterpillars which even though they're kind of soft and squishy they have an exoskeleton like all arthropods do. So, in order to grow, they actually have to shed their skins. And each time they molt or shed their skin, that's called each stage, sub-stage of caterpillars called an instar. So, typically butterflies have shed their skin four times so they have five instars. The moths I work on actually go up to 10 or sometimes even as high as 11 or 12, which is quite a few. So, in order to grow, you got to cast the skin and sometimes the caterpillar will eat their skin, leave no tell tail sign. Other times, they just leave it behind. Okay. So, that--so instar spelled I-N-S-T-A-R.

So, most of my talks prior to this one have dealt with how a specialized group of caterpillars crawl in kind of a slug-like fashion. These are call slug caterpillars and you'll see why soon. I don't really like the name, but I'm kind of stuck with it. But what happen is when I first gave talks on the group, I had all these photographs of caterpillars showing how they crawl, but individual photos, and every time in trying to describe them, I had to get up there and kind of go like this, 'cause they go like this and it got pretty frustrating pretty quickly 'cause that of course I wasn't a good example of how caterpillars crawl, [laughs]. Anyway, so that got me kind off ended the business of doing videos and movies early on. And I still maintain my research status at Smithsonian where I--and as a matter of fact, I guess just a year ago, they did an exhibit that featured my research on the locomotion of these caterpillars.
So, when I say, “I got you back,” that’s what I’m talking about. So, these caterpillars are attacked by various things, by birds, by lizards, by little wasps, so they need to defend themselves. And in particular, they have to because they grow very slowly and they have many instars, so over a two month period they have to defend themselves. So, you’re going to see in this talk a lot of different ways that they do and then I’m going to also show you kind of for an evolutionary perspective how you get--how these different various forms of caterpillars might have evolved, because for one group of moths, these have a lot of very different looking caterpillars. They might look very similar underneath on their belly side, but on their backs, they’re quite different. That one up on the top is actually a native California species and the caterpillar was not even known until about two years ago. And that the moth was common but the caterpillar wasn’t known and that’s because it's fairly well camouflaged and it's not very big. A lot of these caterpillars that we're going to see movies ever kind of about this big and some of the woolly ones are about this big, but that one on top is about this big, and it, you know, we don’t even know what plant it feeds on but I was able to raise it from the eggs, and I'll more into that.
Okay. So, a little bit of a review for those that—I'm going to be talking about families a lot in terms of classification because the family of moth that I am a specialist in is the Limacodidae. But if you look kind of that -- of course look at us, you know we're animals, all these are animals. These are two insect groups. We got honeybees and we got Limacodidae moths. So, if you go down through classification for us of course we're kingdom Animalia, phylum Chordata, class Mammalia, order Primates, family hominidae, genus homo and specie sapiens. In terms of honeybees, you got Animalia, filum arthropods--arthropoda, insecta is the class. The order is hymenoptera, the family is apidae, the genus is Apis, and the species is mellifera. So, I'm going to talk a lot today about Limacodids. And the reason I call them Limacodids, as I said, is I don't really like the common name “slug caterpillar” very much. When scientists talk about their group of research often times what they do is they take the family name so like in the case of bees you would call them and delete the ae at the end. So, if we're talking about humans we could--in terms of their family group we could call them hominids. Then Limacodids -- so you leave off that “ae” and just put an s on the end. Family Apidae, the Apids. So, that's way that you could actually create a common name from a Latin name and learn the Latin name better. Because sometimes common name is really leave a lot to be desired.
Okay, so today we're talking about order Lepidoptera within class insect. And Lepidoptera are characterized by having--well, they're the moths and butterflies, but the name Lepidoptera is derived from a Latin of lepido (“scales”) and ptera, meaning wings. So, all Lepidoptera have scales on their wings and moths tend to look sort of woolly often times and that's because the scales could be modified into kind of hair-like structures, but essentially, they're little--tiny little flecks that can reflect colors. They could have a lot of different patterns. They also serve a defensive function in that if a moth where to get into a spider web they can fly off because the scales become detached from the wings. So, anyway that's Lepidoptera and this is a polyphemus moth. And by the way, when I was on “Fresh Air,” the reason I was on “Fresh Air” is because I was involved in a big coffee table book that had gigantic photographs of moths. And part of why I got involve in the project with the artist Joseph Scheer is that he communicated very well that not all moths are ugly. As a matter of fact, a lot of moths are quite attractive, but Terry Gross never quite got that. She said, "You know, everything are pretty, but you--somehow, how did you make them beautiful? So, just couldn't quite communicate that." [laughter]
This was I guess when I was 4 years old, what got me into butterflies was the “painted lady,” and what happened is that they have a population boom kind of in, like. New Mexico or northern Mexico, in Baja, places like that and they'll--they'll tend to have--it's not really a true migration, but because of the population builds up and they don't have enough thistles. They'll make a northern directional flight. So, when I was 4 years old they hit Colorado in the spring and my brother was 2 years older, caught one, put it in a jar and the sun light shining through the wings, kind of like this picture, just totally imprinted on my brain and that was it, that's what started it all, [laugh] big mistake but you know. [laughter] Not always an easy career choice, but a good one.
Okay, so there's probably about 10 times as many moths as butterflies and approximately 200,000 are known at this time -- and very few of them, contrary to popular belief, are pests. As a matter of fact there are probably a similar percentage of butterflies that are pests to moths. It's just that moths kind of get the bad rap because they end up in your windowsill and of course we have the clothes moth, which is one species of moth. And moth pests are often called worms and, you know, various other things kind of. So, there's a general thought that moths are bad and butterflies are good. But actually butterflies, if you want to really look the genealogy of Lepidoptera -- so in other words the branching tree of life or phylogeny -- butterflies are just a little twig in a big bush of moth groups. So, actually you could say that butterflies are moths.
So, I'm going to talk a little bit about what I do in Sacramento. Basically, I'm the lepidopterist for the state that identifies potential threats to agriculture mainly, but really anything that threatens California's economy, which of course is tied very closely with agriculture.
So, one of my big things is to really be on the watch for what we called invasive species or invasive pests from other parts of the world.
But I also identify a lot of common moths like pantry pests that you get, like Indian meal moth.
And many of the things that I identify are caterpillars, but I also get eggs, pupae and adults -- I get all stages of metamorphosis.
And because this is a state job, not a federal job, my main responsibility is to look out for what's coming in from bordering states, not international ports. But of course we get a lot of stuff from Hawaii and Hawaii gets a lot of staff from Asia [laughs]. So in a sense it's quite a challenging job to know what all the stuff is. We have a collection in Sacramento to help us identify but we rely heavily on the literature and of course we end up with things that we can't identify because we don't have a collection with 200,000 species of moths. So, it's a challenge and of course you remember those 200,000 species each of them has a caterpillar.
Okay, so lot of times this comes in on plants and that can give us a clue because sometimes caterpillars are very specialized in what they feed on. But we also get a lot on beehives brought into pollenate the almonds and various things. That was really big this year.
So this is where I work, we called it “the lab.” It's in South Sacramento and it was built, I guess, about 10 to 15 years ago. They moved from the main headquarters downtown and this is a very nice modern facility.
So, at the lab we have 11 PhD-level entomologists like myself. We also have plant pathologists. So, they deal with the plant disease. We have botanists that are specialized in looking at seeds because of course you can get pests—you can get pest plants, or weeds from out state, out of country that could cause lots of problems, which they have in our state. and we have botanists as well. And then we have nematologists dealing with the little flatworms and nematoids, whatever. And then of course we have support staff that help us and temporary seasonal employees that are there pretty much all year and then administration. So, there's probably a good, I don't know, 50 to 70, I'm not sure that total number in our building. It must be 75.
So a lot of the identifications I do are, you know, using fairly low-tech methods, just the microscope. But of course it helps that I have a lot of experience identifying things. I do use scientific literature, identification keys— I developed them, too.
I also can use electron microscopes for really tiny samples. This caterpillar head is probably, I don't know like--I don't know 0.01 millimeters or something [laugh] -- really small.
We also use molecular techniques for identification, but that's still not as well developed as people might think. A lot of the DNA libraries we have -- I'm actually helping build with pest species so, when we get a caterpillar or an egg, a stage that's very hard to identify, we can, you know, use the DNA more effectively. But I think a key thing to remember about DNA is that, it is really only as good as the identification of the organism is to begin with. A lot of people sort of have this attitude that the DNA is kind of the end all, be all. But DNA, just like anatomical characteristics, has many different sequences and different sequences of DNA can give us different answers. And DNA is variable. And also there's a lot of misidentifications in DNA libraries. So, you might submit a sample and compare it with what's called gene bank or the barcode of life sites on the internet. It might match a 100 percent to misidentified moth. So, that could be a real problem. The problem is that you generate, the new generation may not learn how to identify stuff so, we'll be totally--it could be a real problem. There will be a lot more misidentifications if we don't train people in being able to identify things anatomically -- what we call morphology.
So, a big chunk of what I look at particularly this time a year comes from the sticky traps which you’ve probably seen all over the place hanging from the trees. They form a--I should have brought one--that, you know, they sort of form a little tent and there's sticky goo in the inside and then there is like a little--this little eraser-like thing, that's impregnated with pheromone. So that pheromone has been synthesized from the female moth and it attracts the males. So, you don't get females in these traps unless it's just by accident. So, what they do in California and various other places to survey for pests, they put out pheromones if, say, there has been a find or if they are worried that they might get a find of a pest from, you know, another country, they'll put out this trap in various places to monitor. And we do get things from Africa and various other places that, and recently we got a European pest in Napa that's a major grape pest. So, these traps are very useful, but they're very messy.
And this gives you an idea how many traps could come into our lab. It could be overwhelming and this is my assistant, Obie Sage, who's probably added several years to my life by helping. [laughter]
So, the other thing that's--has become interesting that I never imagine with this job is that I--well, part of it is just survival, when I realized we have a major pest and we don't have good identification tools, I tried to work on developing identification. In this case, an electronic identification key that will help separate out this pest. And generally what happens when California get something first, you know, the other parts of the country want to be able to identify it, too. So, there's a demand for this kind of things. So, I've worked with the US Department of Agriculture and a close collaborator at Colorado State on making several of this identification things. And they're actually kind of fun. I don't know--how many of you used an identification key before? Okay, so what do you like about them and what don't you like about them?

**Audience member**: [Inaudible Remark]

**Dr. Epstein**: Uh-huh. Anything else?

**Audience member**: [Inaudible Remark]

**Dr. Epstein**: Uh-huh, ambiguous, uh-huh.

**Audience member**: [Inaudible Remark]

**Dr. Epstein**: Uh-hmm. Do you ever use a key and get all the ways through like 75 couplets and you don't find what it is? and you spent how many hours and also having to flip pages to all these pictures that aren't with the key. [Laughter] Okay, so what this does is it provides like four little boxes on a page. And in the first box, you look at, there's little check boxes with the pictures of the characteristics. So you're actually not going that, it has a leg, it doesn't have a leg. You pick from a menu of like two or three choices. Just put a little check mark and all these different features of
say a caterpillar or a moth. And what it does in this other box is that it only keeps in the other box, those that are still possible. And it eliminates in the other box, the ones that aren't. So you're actually seeing what are your group of possibilities and what you've eliminated. And it's a pretty neat little system. And, yeah, it doesn't always work. Sometimes you don't get an answer but the other thing about it is it does what we call screening. So it may not always identify the moth but it will tell you it is not the moth of concern. So that's important. So actually being able to say what it isn't can be very helpful. That's a weird concept but it's important.
Okay, this is one of the nasties that we did get but fortunately it did not establish in California but it's a major citrus pest and it did turn up in one of these pheromone traps. But the weird thing is that we did a fair amount of those little Mandarin oranges from South Africa, what do they call them, cuties or whatever, with the caterpillars and this moth in them, they haven't been alive so far, but certainly, there's the possibility that this thing could really do the major number on our citrus industry which has other problems right now.
So that moth actually came—that particular moth is collected in Africa. And probably it would be really easy to say, "Here's an example of a state worker going on a trip to Africa on a Safari to have a good time." Yeah. [laughter] And yeah, well, besides the fact that it's a hell of lot of work and actually can be a little dangerous. [laughter] This is the kind of thing that's actually important because this is where we get some of these invasive species. We get them from all over the world because of world trade. And it's really important for us not only to get the moths but actually get the DNA, you know, have a library of the DNA. So if say we get a pest that we can't identify from the caterpillar, we can get the DNA of that caterpillar and it matches this moth. So, what we're trying to do is build a better resource for identification using all these different tools.
So a lot of this is--these are all moths that have come in for identification. You know, they're on various crops, some of them on grapes, some of them on whatever. That one though in the middle top, that one's laying eggs and that's another aspect of my research. As I mentioned a little bit before, a lot of the caterpillars I study, I actually get from the egg stage. For one thing I know the moth so if I know the moth already then get the eggs then I'll be able to identify the caterpillars. It's amazing how little of this stuff is being done though.
Okay, so here is, again eggs, so I get extra samples but I get eggs for my research too.
I get a lot of caterpillars from all over the place.
And I get the pupil stage, the cocoons, I get chrysalides of butterflies.
Okay, so now I'm going to talk the rest of the time about my research specialty which does overlap with my work duties at times because we do get exotic pests in this group in California. Hawaii has a real problem with them right now but these are called, as I said at the beginning, the Limacodid moth or slug caterpillar moths and they are mainly a tropical group.
But what's amazing about them is this diversity of forms, just very different looking on the backs, again, my talk, I got your back. Well, there's a reason for that.
So this kind of gives the big picture of how many species are in these different families. And, again, remember I talked about families, different families like aphids or bees, Limacodids or the moths, but these are other families of moths that we believe phylogenetically or their genealogy we believe is related to Limacodids. And as I mentioned in the first part of my career and research, at least, I was studying the evolution actually of the locomotion, how they have evolved the special type of crawling which you'll see in a minute.
I hope. Well, I guess they're not going to cooperate. That's okay. So, what these caterpillars have done is they've evolved a special form of attachment to smooth surfaces. I mean these caterpillars in captivity love to be on the side of a jar, more than a plant. [laughter] As a matter of fact, I call it the Teflon test because you put one of these caterpillars, especially a Limacodid, the bottom two. Let's see. Let me get that bottom one going. I set one ago. You put them on glass, turn it over and they stay, and they just keep crawling. You put in actually any of these related ones, they don't, they fall off. But other caterpillars will fall off too because generally, caterpillars, what they need to do to cling to a smooth surface is spin a lot of silk and then they have hooks on these fleshy legs on their abdomen. So caterpillars, of course, have six legs like all insects, like the adult stages but they also tend to have what are called prolegs which are on their belly, on their abdomen. And those prolegs are what actually hook them onto the silk which hook them onto the plant. But of course they fail at the Teflon test because they don't have the opportunity to lay all the silk down to hook on to.
Okay, so now you get to see a little more close up. So this Megalopyge which loosely translate into big rear end is—which got my cousin in a lot of trouble because he called his girlfriend this. [laughter] It's really bad. And I never heard the end of it and they broke up. [laughs] But it wasn't my idea. And she didn't, actually. But these things have evolved the extra prolegs. So typically, caterpillars have five sets of these, these have seven. So basically, it almost appears that every segment in these caterpillars is actually hooking on to this narrow wire. So this is kind of the first stage in the evolution of this group is to actually have an addition of a characteristic which is rare in evolution. Things get lost a lot easier than they get gained. But somehow there were some, through natural selection, you know the ancestral type of this group had the extra legs which is prolegs, not extra. We don't have any insects that have added thoracic legs. The six legs are very much a fixed thing but the prolegs are not, as I've learned.
So this is another little group. And this one is sort of in dispute whether or not this family is a family or not, whether it's with the wooly one that we just saw. But what's interesting about it is that it's kind of on its way to having what we call the sucker discs on its belly. So, each one of these little things that's kind of grasping as it—you see the little peristalsis, we call that a wave that goes kind of from rear to front but it can also go on reverse. It's amazing. They can go either direction, really amazing mechanism. So what they're doing is that they have muscles that are pushing down and they're hooking on to—in some cases, hooking on a silk but not in this one. But they're basically squeezing their hemolymph which is their blood, from one end to the other. Remember, insects have what's called an open circulatory system so they don't have veins and stuff. So, they're basically awash with their blood which is called hemolymph. So, the muscles squeeze the hemolymph from one end to the other. But normally, caterpillars like inchworms are crawling around like that. So they don't have very much connection to the substrate or the smooth leaf surface like this does.
And here you can see it using its silk. And hopefully you can see it kind of hooking on with it. So, those tiny little legs at this end are the thoracic legs. So there are six legs here and they’re kind of hooking on to the silk. But then on each of these, little sucker disc pads, they have hooks too that are hooking in to the silk. And notice also that the head is doing what we call a figure eight. So they’re putting the silk down in a figure eight fashion. A lot of caterpillars do that. And, of course, you see the silk on the glass. Yeah, I should mention these are on glass or plastic, or whatever.
Okay, so here's the limacodid type. And basically have done away with all the hooks, all the prolegs, basically just squeezing the hemolymph from one end to the other. So this is kind of, you know, where the evolution has gone. And actually it's been very successful. This is the biggest group in the superfamily. And actually, when I started my research, I didn't even realize it. I thought it was about the same as some of the others but it's actually has about 1,700 species.
So, here is a view of that from the side. And here you get an appreciation of the fact that they do have muscles because they would not be able to grip the stem without muscles.
Okay, and here--so what would you call this type of silk spinning that we saw before in the ancestral type?

**Audience member:** Figure eight.

**Dr. Epstein:** Yeah, figure eight. So here you're getting the figure eight but notice the silk, it's a little different. It never really dries. It's a ribbon as opposed to a strand, and that's still a mystery whether this is something in terms of are they through their mouth, are they like here, or is there like fluid coming out of their mouth when they put the silk down, or is it just that the silk never dries. Because in order for silk to tan, it's a protein and you have to actually pull it off from the leaf. So is it a behavioral thing, is it physiology, it's still not known. Hopefully, it will get worked out pretty soon. I have a group at Oxford that wants to work on it.
So this is what the spinneret looks like. But what's interesting is when it actually changes shape as the caterpillar grows. And it's like a lot of things I'm going to be talking about. But what's interesting is not only does it lay down the silk but it also serves as a brush or a mop. Because these caterpillars are very sticky underneath, they actually need to kind of rear themselves up off the leaf and clean themselves off because everything sticks to them. So these are like little brush type features of the spinnerets. So the silk comes out like here but then you got all these little baffles and other things. And then the rag moth as I call it, actually helps it when it builds its cocoon because they squirt all these white calcium oxylate fluid out. And these type of spinnerets will make this really special hard cocoon. This looks like a tiny little bird egg. And then they have a little lid that pops out when the pupa emerges. That's why in Australia, they call them cup moths because you find old cocoons that the top has been popped off and they look like a cup, a little ceramic cup.
This is what a typical spinneret looks like and most Lepidoptera. So you could see that part of the evolution of the slug caterpillar, it's a very specialized type of spinneret. This is one of our leaf rolling moths in California.
So, how do we explain this diversity of forums that I keep talking about? Okay, so as I mentioned before, they grow very slow. They have many instars, up to 10, 12. So, they feed slow on top smooth leaves which they're adapted to be on. So they're exposed for long periods. So they're out there, you know, a butterfly might take three weeks or a moth, a week and some of these other moths, very fast, go through metamorphosis. So they're not out in the environment or they may be feeding inside a leaf, inside a stem, you know, really protected. These things are out on the surface of the leaf. So, now I'm going to talk about the defenses that they use.
So this is most common in the group, probably about 75 percent of the known Limacodidae caterpillars of the 1,700 species. We don't know the larvae of all those but we can make a pretty good guess because related—in related genus or we don't have subfamilies yet but related groups tend to all be the same. But anyway, these spines protect them.
And here is an example of how a saddleback protects itself from a wasp. And at the end, you'll see how a poor lowly little cut worm caterpillar doesn't have any defenses.

Here's the victim. It's about ready to get nailed.

Not much success. [ Laughter ]

So it works, sometimes.
Okay, here is where it fails. So these tiny little parasitic wasps have a feel they were the same type caterpillars. So they're able to get in there and lay their eggs. And then what you're seeing on here aren't eggs, they're actually little cocoons of the parasitic wasps. So you can actually see them spinning their cocoon on the back of the caterpillar. So inside of that is a little--basically, a little caterpillar of the wasp and it's spinning away. And that's what--I'm sure you've all seen pictures of this. When I was a little kid, I used to think they look like Rice Krispies. Oh yeah, and there's another little thing that's interesting is notice these little cups here, it's almost like with the Limacodid cocoon, this is where the adult wasp will pop out of the cocoon, that little lid.
Okay, so you’re seeing pictures of these caterpillars on kind of flat leaf surfaces but what they do when they’re in their later instars like after the third or fourth instar, what they do is they start feeding on the edges of leaves. So all these pictures were taken, all these movies were taken where the rest of the caterpillars on the other side. And what I call this is cryptic feeding. So remember, all these pictures that are taken, they're highly magnified so you see all this movement. But in nature, when you see these caterpillars on the edge of the leaf, you can hardly see them because they actually eat with their mouth closed. I mean not literally but what they do is they take their thorax and the thorax covers the edge of the leaf where all the movement of the mandibles and all the chewing is occurring underneath the thorax. So that little dot there, that's not an eye. What that is that's actually where they breathe out of, that's called a spiracle. And most segments of caterpillars have these things. But you really—underneath, there's all kinds of action but you're not seeing it. And that— not only that but it's also muffles the sound so--and that's something that would be really interesting experimental work to do, to look at, you know, what detects the sound, what doesn't. When you're in the rainforest during caterpillar season or even in the eastern US, you hear the caterpillars in various ways but one way is the chewing because you have so many of them. You also hear their frass which is another story.
And speaking of frass, what these caterpillars do is they fire frass off the plant. So why do you think they do this? Of course, the answer is at the bottom but--[laughs].

**Audience member:** To confuse predators?

**Dr. Epstein:** Yeah, yeah, they--it's a really good--either confuse them or not, they won't be detected because they don't keep that frass. What else do you notice about this little pellet though? There's something different about--of course, I don't have a regular piece of frass to compare it with. But notice how it's kind of hollowed out. That's actually a specialization that's not found, as far as I know, in any other caterpillars. So what these things have evolved is some way of making their little frass pellets into kind of a hollowed out thing that when they squeeze it, it fires. So that's another unanswered question. What kind of specialization internally do these have to be able to make these special? And I know it sounds ridiculous but there are specialists that work on frass ejection in caterpillars, I'm not one of them but. [laughter]
Okay, so this is the defense that I showed at the beginning of the talk. But what's interesting about this--which you could call it like see an enemy at defense. The way these spines spring out, they're sea urchins or. I don't know if you've noticed this but these caterpillars kind of remind one of sea creatures in a lot of ways. They look kind of like sea slugs. They move in angulated ways. They're--they have bright colors. They have these kind of defenses.
So another type of defense is what we call group feeding. So, and of course, these tender eggs are laid in big clusters and they stay together throughout their lives. So the idea that some of the caterpillars will get nailed by predators or parasitic wasp but not all of them, and then they’ll build group cocoons also which incorporate some of their spines in there to protect them.
Okay, this kind of droplet defense is another limacodid mystery. We don't know the chemical makeup of these droplets but we're assuming that they have some kind of noxious quality.
And then we also have these little warts that remove and actually will grow back if this occurs in early enough stages. Notice a little wiggle at the end there. So kind of like a lizard's tail, they still have a little nerve firing going on there.
So, these are examples of—we've seen the spiny defense but also you have camouflage. And sometimes the camouflage reflects very much the type of plants. So in other words, this one up here is a fern feeder. This one is on mistletoe. It has the mistletoe berry pattern. These are a little more general but yeah they could be very, very hard to find.

**Audience member:** A quick question.

**Dr. Epstein:** Uh-huh.

**Audience member:** Do any of those spines have any kind of a toxic thing on them?

**Dr. Epstein:** Yeah they do. They have pretty nasty venom. And part of the problem with doing their chemistry is that it—they are very unstable chemicals. So I know there is some kind of—what are they, histine, histamines versus antihistamines. So, when they—when you got stung by them you tend to, well, you see pictures of them in literature, people being stung by like a whole caterpillar, they have an imprint of the caterpillar. So basically all the spines get you, and it sticks around, and that hurts a lot. And I've never tried it myself. [laughter] The thing is though about caterpillar stings is that just handling them, a lot of times, you don't really realize how calloused your fingers are, it's more the back of your arms and whatever.
Okay, so again, there's got to be a lot of selection pressures to produce all these different types. So let's talk now a little bit about how these various forms may have evolved. And I'll give you a little clue. I think it has a lot to do with what we call ontogeny or the development. So remember, we have a lot of instars in this group. So they have a lot of opportunity when they cast their skins to have what we call heteromorphosis. In other words, the different instars can look very different. So a lot of changes can occur in the different little instars in the different stages of the caterpillar. So we're going to talk first about Harrison Dyar a little bit who did the first phylogeny based on the caterpillars.
And these were all from New York State and this was done in 1899. And actually, it's held up pretty well, his genealogy of the caterpillars. As a matter of fact, Dyar did his own family genealogy at the same time and he did identical trees, it's quite something. I mean not these limacodids on there but the Dyar family names are inside the tree in the same style as he did these and his other genealogies were done with stick figures so he had a special affinity for this group.
So, if we plot on to Dyar's tree, what the different caterpillars look like, you know, we have all spinies over here. All smooths over here. This is the smooth one with the droplets. These don't make droplets. So kind of two big groups with a split down here. And he thought of this one, the hag moth as being the most primitive of the--and because it's woolly, kind of woolly and it's not so spiny but more woolly.
Okay, so these are the smooth, those are the spiny. Okay, so this another really—it's kind of an obscure thing in his papers but what he noted was that when these caterpillars that are smooth hatch, they feed right away which is typical of caterpillars. Almost all caterpillar, I mean a hungry caterpillar, they're going to feed. I mean, why wouldn't they feed? But what's interesting is these that are spiny actually fast for a day and then they shed their skin and become the second instar. And the one exception interestingly enough is our woolly hag moth, the one he considered the most primitive. So those actually feed too. So that's like the one exception to the rule.
So, Dyar is known for his law of geometric growth which I don't have time to go into. But he also has what I call Harry Dyar’s Law which is a bad pun but the idea that hairy caterpillars are the ancestral type of limacodidae.
And this sort of goes along with, you know, like how we think of our relationship with, you know, the chimps and the gorillas, the mastodon to the mammoth, everything goes from woolly to smooth. You know, that's sort of the general evolutionary trend that's always assumed. And the case of limacodidae is kind of from hairy to smooth or spiny.
So, here's an example of going from spiny to a spiny group of seedy, two, just two, two little hairs versus a whole clump of spines.
And what he didn’t know is in some of these examples, if he had actually been able to see the caterpillar stage, the first instar, the one that when it first hatches out of the egg, his assumption was that they were spiny all the time but actually you have the two fetal condition that he thought of as derived is actually the primitive case. So he got it reversed, the evolution of the spines were reversed because he didn't have all the evidence.
So, sorry I waited so long to tell you this but Dr. Dyar was in Chico and it was back in 1906, and a matter of fact, I don’t know if you can read this little label from his catalog but he collected in his room on July 13th, 1906 at Chico, California. And so he was on his trip collecting mosquitoes like you see here looking for the larvae, panning like a gold miner. I made this little video because I had a couple of different pictures of him.
So, anyway, what's the mechanism for this evolution? So, as I've kind of hinted I think ontogeny or developmental advance, there's a fancy term, heterochrony involved with timing. So, the idea that why you've all seen pictures of the human embryo and—versus other creatures and the fact that humans are born kind of helpless whereas other creatures are more developed when they, you know, that whole thing. So that's an example that we all know about just different timed events. So you can look at the caterpillars in that way which is pretty instructive.
So I'm going to give you some examples of what happens between first and late instars. And what's interesting is the related families to limacodidae, the Megalopygidae, Dalceridae, aphids, all of them. They basically change very little from early to late instars. These start out spiny, end up spiny. These start out smooth, end up smooth. And kind of what's interesting is these all have kind of volumetric eggs. So they're not the flat scale type. So in other words, there's plenty of room inside of those eggs that have a thick eggshell to kind of develop. So keep that in the back of your mind.
Okay, so hairy, hairy, smooth, smooth, spiny, spiny.
Okay, so the nettle type limacodid caterpillars, it's a very different story. They add a lot from early and they start out with kind of simple what we call tubercles kind of fat and seedy with very few kind of none things and then they add a lot later on. And they have a very, very flat egg with a very thin eggshell.
Here's another example. So this is what the first instar spine looks like. Here's what they look like in a second instar when they start feeding. Remember, I talked about fasting and feeding? This is a group that fasts and then there's many changes after it molts or in other word sheds its skin, becomes the second instar, gains all these spines.
Okay, so now on the smooth limacodid end, they also--they go from spiny to smooth. So these are the feeders. So these feed right out of the egg.
So, here's--this kind of shows that kind of about the extremes of this diagram are ones that changed very little from first to late instars but all these in the middle have big changes, these have moderate changes. So we could call these at each end, precocious. In other words, they're basically like the late instars. They hatch out. They don't change much. They really piss me off because I'm hoping with first instars, I'm going to get characteristics that will give me clues on how they're related to others but they provide me with very little. However, I have learned to appreciate them because it really shows the importance of these timing events.
Okay, so here's the same caterpillars, what they look like late instar. Those earlier ones were taken with electron microscope, they're like a millimeter. These are like, you know, a centimeter or more.
So, I guess to answer this question about why you have these diverse forms, essentially you go from looking fairly similar to looking quite different. In some cases, other cases, they just don't change much, so you got all this going on.
And this is in kind of the tree of life. And what's interesting is the DNA evidence is now showing that, in fact, this hairy larva that feed in the first instar belongs with all the smooth ones. So in other words, this one really doesn't change much from the first to late instar. We've always thought of it as being so different but essentially this all start out about the same, it's just that one doesn't undergo much change whereas these guys, all fast. So you have--it's interesting that the DNA recovers the data that the fasting larvae are all one group which is a derived feature in evolution. That's a uniquely derived feature. Whereas the primitive case as you would expect is feeding. I mean, yes it's--I guess there's always this thing about, with evolution we like to think that things that are common are primitive, that's not always the case but in this case it is. Well, actually it isn't really because these are actually much more diverse, just the 75 percent of the group fasts, only 25 percent has them. So actually that's a good example of primitive being less common.
Okay, so as I mentioned before, there is a correlation between the egg shape and the behavior and I won't spend a lot of time on this now.
So, we could think of the first instar fasters is the ones that are waiting to molt the next day. And as a result of this constraint you—that's how you can get a spiny larvae out of the flat eggs by not molting right away. I mean not coming out spiny.
And it would rupture if you had a spiny larva underneath that thin egg. And as a matter of fact, limacodid eggshells are the thinnest known Lepidoptera.
And the other factor is that the eggs of the spiny ones are usually laid in clusters. So in fact, if they fed right away they might eat each other which could be not so good.
Okay, so here's some examples showing the spinies when they first hatch. And they just sit around, sit around, sit around for—it's very frustrating at first until you realize what they're doing. Notice how when they first hatch these are sort of the yellow color but when they're about ready to molt, you can see all the black there, that's all the spines underneath.
Okay, so here's an example of our California one that was not known 'til three years ago. So, this shows looped, what they look like when they hatch out. And notice all the little individual spines, kind of nibbles on the egg a little bit which is interesting but it—which makes sense because they're about to start feeding but they don't feed until they get to the spiny.
Okay, so reiterate, first instar feeders. Okay, those are the smooth ones generally and they don't have the constraints because they're not a spiny. And they don't lay their eggs in clusters. So that also makes a lot of sense because then these individual eggs are out there, they hatch out and start feeding right away, they won't eat other.
Okay, so here--shows what happens when--the other thing is--that's important to keep in mind is that even these that becomes smooth, they telescope out their spines after they hatch. So they're like inside of them and then they're pushed out. And you can see if you look at the bottom of this egg hatch in time lapse, see how it's becoming spiny? So that's another aspect to this thing that's important. But this one will feed right away.
Here's another, this shows the telescoping I was talking about. So when they first come out, these spines are internal and they get pushed out all the way like this. This is one is actually pushing them out as he's being filmed.
These are on--I don't know. Are you familiar with ocotillo in Arizona? These are time to feed on the ocotillo in July after the rains. So the moth spends the winter in a cocoon, comes out with the rains, the monsoons, and they lay eggs on the ocotillo. And then the ocotillo loses their leaves later so then, you know, these would.
Okay, so here's an example of the groups outside of limacodidae. I mean they do like most Lepidoptera do because they feed right when they hatch.
Here's another example. So this one is spiny but, of course, these--remember that these related groups don't have the thin flat eggs, so that's very important. They can pop out, they're precautional in a sense, they're ready to eat.
Okay, so once again here's this business.
I don’t need to talk about it anymore. And this kind of shows—kind of if you were to just look at the evolution from a first instar point of view, this could be how the characters transform.
And--but if you were to look at that from the point of view of the late instars which a lot of people do, they just find a caterpillar and say, "This is the evolution." They ignore all the other information. You're missing a lot in terms of understanding kind of the evolution of this group.
Okay, and again these are the spinies among the gelatins.
And so, basically these might look like hag moth or nettle caterpillar but they're not.
So, here's my conclusions. So, these various forms and shapes and defenses really appeared to, you know, be from intensive adaptive pressures from enemies.
And the timing and development is a mechanism that explains much of this formed diversity.
And the fasting of spiny nettle caterpillars which again is about 75 percent plays a role in overcoming developmental constraints from a thin flat egg.
And then feeding when hatching is primitive, no surprise there.
Okay, so one final bit of philosophy, architects often look to nature for inspiration. And this is just the back of a caterpillar but I guess it could look like a statue with a rainbow or something or beam-like.
Certainly Gaudi in Barcelona looked at a lot of natural things, a lot of mountains to get his inspiration. I don’t know if he looked at caterpillars but I certainly see them in his work.
But I really do think that Curtis Fentress [laughter] very much might have seen this caterpillar. [laughter]
DID HE HAPPEN TO SEE ONE OF THESE CATERPILLARS?
And that's the end of my talk. And--
[ Applause ]
Any final questions?

**Audience member:** Question, we're talking about trapping the moths--

**Dr. Epstein:** Uh-huh.

**Audience member:** --using a pheromone, is that specie specific?

**Dr. Epstein:** Yeah. Well, it's supposed to be. And that's part of the problem. The pheromones used often attract related things. Or because you have sticky traps, you're going to get a lot of moths anyway. And also, pheromone traps will get the odd female and, of course, the female stuck in the pheromone trap, its pheromone will go out and attract the males. So, I know people think that when you're monitoring using pheromone traps, it's like this perfect system where you're only going to get the pest but that's part of why it's so much work. And then, of course, to identify some of that stuff that's been in a sticky goo, you have to remove them using solvents and can be pretty messy. Any other questions? Uh-huh. [Inaudible Remark] From what? [Inaudible Remark] Okay there is a number of different points but basically in terms of that kind of the genealogy of the group and phylogeny, it looks like the evolution of fasting is significant. And then the fasting relates—at least, the best explanation I can come up with at this point is just that it allows you to get a spiny caterpillar from a thin flat egg. And, of course, the question is why would you want to have a thin flat egg? Well, one reason is that they're pretty hard to find. And so, and also they don't spend a lot of time in those eggs. So they put much in their resources in the eggshell [inaudible]. Uh-huh?
Audience member: [Noise & Inaudible Remark]

Dr. Epstein: That's a very good question. Of course, it's a day, well, that's a day that they're pretty vulnerable. So, yeah it's kind of--yeah, a lot of them grown actually. But what's interesting--that's a great question because there's been a recent discovery. See in museum collections for years there have been all these little tiny wasps that nobody ever knew how the made their living. And it turns out, guess what? [laughter] They attack early instar limacodids. So what happens is that these caterpillars actually live because they house these little parasitic wasps. So they don't die right away but eventually they are killed but this whole group was never found. And what's interesting is in Costa Rica where we have the most information about the parasitic wasps, these weren't detected there either and that's because, you know, most of these are dead by the time that you would find them. So this whole group, the only parasitic wasps we know are the ones that attack later in the stage [inaudible] this caterpillar and so this whole guild of things that attacked [inaudible]. And of course the whole thing about, you know, being parasitized or predated or eaten or whatever is we will be covered with caterpillars if these things didn't happen. So, the mortality is huge with caterpillars. And that's why you have so many eggs. I mean for every hundred egg probably, you know, three or four caterpillars survive or become adults or whatever.

Audience member: Well maybe if there were more questions, come on down. And if otherwise, thanks so much--

[Applause]